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On the planning and analysis of Integrated Community Energy Systems: A review and survey of available tools

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ABSTRACT

Highly Integrated Community Energy Systems (ICES) greatly but not solely dependent on combined heat and power (CHP) sources are a viable approach for dealing effectively with the new set of global threats which Mankind is facing, such as Climate Change, Global Warming and Extreme Poverty. ICES are capable of delivering sustainable electricity, heat and cold to small communities and of working as grid-connected or islanded microgrids, adding technical, economical, environmental and social benefits to populations. The impacts of introducing ICES in current distribution networks can be analyzed at different scales due to the wide range of influence exerted not only at the local but also at regional and global levels. For these reasons, there is increased need for appropriate modeling of ICES for the vital purposes of planning and analysis of these systems. An overview on the available bottom-up tools for the optimization planning and analysis of ICES is done in this paper. The survey shows that DER-CAM can be considered an appropriate tool for the purpose of ICES design modeling due to the robust and flexible three-level optimization algorithm, hourly time step and other scale considerations but particularly due to the several successful applications with modeling microgrid systems. Additionally there is research experience on expanding the objective function for environmental concerns and also with EV battery storage interactions. Finally, GAMS DER-CAM's base language, is a widely known package for allowing changes to be made in model specifications simply and safely. In that sense, there is potential in exploring such tool for the design of ICES. Furthermore, it is found that MARKAL/TIMES, also a GAMS/CPLEX based tool, has scale flexibility which enables it for analyzing the long-term deployment of ICES in time. There is opportunity in this field for further work exploring the sustainability-sound modeling for optimal design of ICES and deployment scenario options evaluation, through long-term time horizons consideration.

Contents

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1. Introduction

Energy has become one of the major issues discussed worldwide on the entry of the new millennium. Global concerns such as Climate Change and the Kyoto Protocol compliance, energy security, renewable energies and energy efficiency are now considered top priorities to address by most governments. Additionally, in countries such as the United States of America (USA), the United Kingdom, Germany, Spain and Portugal, the global financial crisis has paved the way for renewed recovery policies focusing on reducing energy dependency through increasing the penetration of renewables and the aggressive promotion of broad energy efficiency measures. Effective joint implementation strategies emerged from both the European Union (EU) countries and the USA, such as the 20-20-20 climate and energy package targets and the Clean Energy Policy set of measures by US Government, addressing very strict and demanding goals for gradual fulfillment in the years to come.

In this exceptional context, the sector has been given several economical and regulatory incentives whose objective is to promote the effective implementation of actions to cope with the established international targets. As a result, essentially pushed by new environmental and political goals of governments, a climate of technological innovation emerged and a strong impulse occurred towards the diffusion of new energy systems and new investments in clean energy technologies (see Fig. 1).

The New Millennium Development Goals, established by the United Nations, added renewed priorities to an already complex scheme of global obligation policies and internationally agreed measures, introducing between other endeavors, poverty eradication and environmental suitability as absolutely essential priorities to consider by the member states and international organizations and to achieve globally by the year 2015.

One such path unavoidably calls for highly integrated approaches on designing new systems, from both Industry and the Scientific Community, addressing these issues with a widespread view, taking into account technical, environmental, economical and social issues, thus drawing new attention to the full-broad concept of Sustainability.

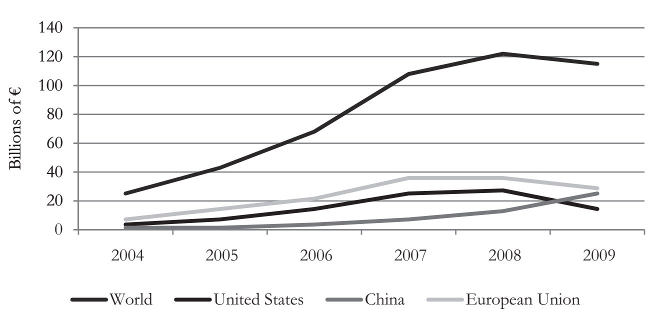

Fig. 1. Growth in worldwide clean energy investments from 2004 to 2009. Included in the accounting are a wide range of products and services such as several renewable energies, nuclear energy, biofuels, alternative vehicles and transportation efficient technologies, carbon capture and sequestration and a broad array of energy efficiency measures applicable to commercial, residential and industrial facilities. It is worth mention the fact that for the first time China invested more in clean energy technologies than the United States in 2009. Also, the downturn in 2008 and early 2009 reflects the global economical recession.

Adapted from [1].

The development of Integrated Community Energy Systems (ICES), capable of delivering sustainable electricity, heat and cold to small populations and of working as isolated islands or as a backup of the distribution network, emerges in this context as a viable approach for dealing effectively with the abovementioned new set of global problems. In this logic, a significant part of the solution for energy global issues may be found by exploring the potential and the integration of community energy systems. In fact, this analytical approach encompasses concepts related to Systems Theory, in which the contribution of a lower subsystem to an overall system efficiency must be considered. The famous community planning motto “Think Globally, Act Locally” could not make more sense, in this context.

The need for appropriate modeling for the vital purposes of planning and analysis of energy systems comes naturally with the rapid development of technologies and policies. Modeling community-level integrated energy systems calls for detail-based approaches, capable of delivering economically, environmentally and at some level socially compromised outputs. Such approaches are rare within the literature; Jebaraj and Iniyan [2] did in 2006 a general review on the different types of energy models, aiming to provide support literature for helping the energy planners, researchers and policy makers widely. In 2009, Chicco and Mancarella [3] reviewed the novel concept of distributed multi-generation, exploring slightly the potential of ICES and of microgrid-managed energy-integrated districts. In 2007, Hiremath et al. [4] did a review on the modeling and application of decentralized energy planning. For last, in 2009, Connolly et al. [5] performed one comprehensive review on 31 computer tools for analyzing the integration of renewable energy into various energy systems. In general, these studies point to the conclusion that current energy-environmental modeling packages are rarely used at the community level and thus that is necessary to develop more consistent criteria leading to integrated approaches. As to social aspects, constraints to the problem such as employment factors are sometimes used, but due to scale considerations of economies they are hardly referenced at this level.

This paper presents an overview on the available bottom-up tools for the optimization planning and analysis of Integrated Community Energy Systems (ICES), addressing special concerns to the incorporation of the environmental, economical and social aspects of Sustainability. Before, particular attention is given to the background frameworks which are closely in the basis of this practice, namely, the historical path of the application of optimization techniques for the planning of distribution networks, of distributed generation, microgrids and of ICES. The explanation of how System’s Thinking theory relates to the design of energy systems and how it leads to asking the right questions to look for in the modeling of ICES is also done.

2. Background framework

The next chapter highlights the framework concepts and context in which ICES planning emerges, namely the development and historical path of the optimization techniques for the purposes of distribution networks, distributed generation and microgrids planning.

2.1. Distribution systems optimization planning

Distribution networks are the closest part to the consumers of the skeleton of conventional centralized energy systems. The development of optimization techniques for the planning and operation of distribution systems has been a common practice for many scientists and engineers for the last decades and a variety of approaches have been experienced ([6,7]). A general representation of these problems, as in most optimization problems, can be expressed as follows: Find the minimum of one[2] objective function f defined from one set A to the real numbers, subject to the constrains g and h, such as:

$$f(x): A \to R$$

$$\begin{aligned} &\min f(x) s.t. \\ g_i(x) &= 0, \quad i = 1, \ldots, k \\ h_j(x) &\leq 0, \quad j = 1, \ldots, m \end{aligned} \tag{2}$$

Being k the number of equality constraints, m the number of inequality constraints and x the decision variable.

As it is difficult to find the global optimum solution to this kind of problems, due to the large number of possible combinations, many approximation algorithms were developed to attain near optimum solutions (approximation algorithms).

The first approaches to solve distribution networks related problems were developed in the 70s and, as stated by Nara and Song [7], corresponded to merely mathematically heuristic methods. In the early 80s, expert programming aid and artificial intelligence techniques are introduced to solve the problem, however [6,7] state that these results were not satisfactory for complex problems. In the 90s, along with a number of linear and non-linear representation techniques, bottom-line approaches capable of simulating physical phenomena and evolution biology are proposed to solve the combinatorial optimization problems of mathematical Heuristics, attracting the attention of many researchers in the area. At this point the Modern Heuristics or Metaheuristics theory was born.

During the last twenty years, many metaheuristical methods have been applied to the distribution systems planning area. The developed techniques are now diversified including Simulated Annealing (SA), Genetic Algorithms (GA), Tabu Search (TS), Evolution Strategies (ES) and other advanced methods such as Artificial Neural Networks (ANN), Ant Colony (ACO) or Particle Swarm Optimization (PSO). Nara [6], Nara and Song [7] acknowledge in 2000 and 2002 that SA is the dominant technique applied in the distribution planning area between 1990 and 1996 while GA takes a part from 1996 to 2000. The authors also conclude that from 1999 TS starts to emerge [6].

In the early 90s, authors like Chiang and Jean-Jumeau [8], Chiang et al. [9], Darling [10], Chu et al. [11], Billinton and Jonnavithula [12], and Jonnavithula and Billinton [13] presented a group of publications proposing SA to solve optimization problems in distribution systems planning. SA emulates the physical process of annealing of metals, being generally considered a flexible technique whose main advantage is its applicability to large problems regardless of its conditions of differentiability, continuity and convexity that are normally required in conventional optimization methods [14].

SA is nonetheless pointed by numerous authors as a computational-heavy technique. The search for soft computing methods was still mandatory. Nara et al. [15] in 1992, Miranda et al. [16] in 1994, Yeh et al. [17] in 1996, Ramírez-Rosado and Bernal-Agustín [18] in 1998 and Chuang and Wu [19], Chen and Cherng [20] in 2000 used GA as an alternative method for solving the same problems. The objective was to get approximate global optimums with less computational burden, comparing with SA. GA are a particular class of Evolutionary Algorithms (EA) that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover and are based in genetics common concepts such as generation, reproduction, natural selection or fitness.

TS emerges as a new approach to solve distribution problems through Huang et al. [21], who concludes that comparing with SA, nearly optimal solutions are attainable within less computing time. Huang et al. [21] also encourages future practical applications of TS for combinatorial optimization problems. According to Lee and El-Sharkawi [14], TS is a greedier algorithm than SA and GA, thus exploring the solution space more aggressively. Nara and Hasegawa [22], Ramírez-Rosado et al. [23] followed, along with Gallego et al. [24], Mori and Ogita [25–27], Ramírez-Rosado and Domínguez-Navarro [28] and Navarro et al. [29] with diverse successful applications and problem approaches in the field of distribution systems.

Swarm Intelligence relates to the use of algorithms inspired from the collective behavior of species that compete for foods such as ants, bees, wasps, termite, fish, and birds. According to Talbi [30], in Swarm Intelligence-based algorithms particles are simple and non-sophisticated agents which cooperate by an indirect communication medium and do movements in the decision space.

The most popular swarm techniques are PSO and ACO. In reliability studies, Kurutach and Tuppadung [31] applies PSO in a radial distribution system to allocate the most appropriate positions to place sectionalized devices in distribution lines. Many encouraging advances in PSO elevated its capabilities to handle a wide class of complex engineering optimization problems. ACO mimics the foraging behavior of real ants, which are not only capable of finding the shortest path from the food sources to the colony without using any visual cues, but also of adapting to unexpected changes in the environment. ACO has also been largely applied to distribution system area in the last years. In 2004, Gomez et al. [32] used ACO for minimization of the fixed costs correspondent to the investment in lines and substations and the variable costs associated to the operation of a distribution system. The authors [32] conclude that this methodology is a flexible and powerful approach, allowing the development of a complete and detailed model of the system and a significant reduction on the computational effort compared to high-performance GA. Ippolito et al. [33] presents a dynamic multiobjective algorithm, based on the ACO Search (MOACS) and on Pareto optimality concepts for solving the strategical planning of distribution systems. A number of authors continue to successfully apply ACO for distribution systems planning such as Favuzza et al. [34] who represent via a dynamic ACO Algorithm an optimal reinforcement strategy to provide reliable and economic service to customers using gas-fired microturbines.

This historical path demonstrates that the metaheuristic theory can be considered the current main trend on optimization methods for solving most of the problems which have emerged in distribution planning systems area. Mention should also be made to a set of Pareto-based techniques which are being successfully applied to this field of research. Rivas-Davalos and Irving [35] for instance, test the application of the SPEA-II algorithm to the distribution planning problem using two objective functions with acceptable results. However, in the following years, the problem became even more complex and difficult to solve.

2.2. Introducing distributed generation and microgrids

Deregulation of the electricity markets paved the way to an important change from monopolistic economical circumstances to an oligopolistic structure to incorporate competition amongst

[2] In multiobjective optimization, the representation assumes the form

$$\min F(x) = [f_1(x) + f_2(x) + \cdots + f_n(x)] \tag{1}$$

where f_i is the ith objective function, n the number of objectives and x the decision variable.

Independent Producers (IP). Additionally, with the introduction of Distributed Generation (DG) and of its ability to solve the conventional distribution grid capacity problems, planners are faced with new challenges. DG generates electricity and optionally heat and/or cold from a variable number of small energy sources, comprising an alternative approach to the traditional energy paradigm. The concept of DG lies basically on bringing energy generation close to the consumer, thus reducing all the complexity, costs and inefficiencies associated with the large transport and distribution networks. According to Dugan et al. [36], the pressure to consider DG options for capacity addition comes mainly from:

1. Investment risk in competitive energy markets;
2. Regulatory agencies that require due diligence before approving major investments;
3. Increasing availability of cost-effective DG technologies.

Other known key factors, which are in the basis of the growing pattern of DG introduction, are its high efficiencies associated with low investment costs, small sizes, modularity and most significantly, its ability to exploit renewable energy resources [37]. According to [36], the need to consider DG has shaped the tools utilized at the moment and will continue to do so in the near future. In Dugan [38], the authors define the twelve most significant technical challenges for planners to overcome in the next years. Those are:

1. Voltage change screen;
2. Overcurrent contribution screen;
3. Open conductor screen;
4. Islanding screen;
5. Power flow studies of various types;
6. Annual simulations;
7. Detailed islanding studies;
8. Harmonic analysis, especially if the DG has characteristics known to produce harmonics;
9. Inverter interaction with the distribution system;
10. Insulation coordination;
11. System unbalance analysis: impact of one-phase DG or impact on system negative- and zero-sequence values on the generator;
12. Short circuit analysis.

One can consider two major classes of DG analysis, taking into account the connection of DG to the typical utility distribution system [38]. The first four listed challenges refer to screening applications, in which utility engineers have a short time to respond to non-utility proposals to connect DG to perform the usual detailed studies. The remaining items are related with detailed interconnection and impact studies with less severe time constraints than for the screening studies.

In the beginning of the 00s some authors start exploring the methods for optimizing the deployment of DG in conventional distribution networks. Celli and Pilo [39] acknowledge in 2001 the necessity for flexible electric systems studying the use of GA for solving the economically optimal allocation of DG on an existing distribution network, considering a number of technical constraints such as feeder capacity limits, feeder voltage profile and three-phase short circuit current in the network nodes.

In 2003, Mori and Iimura [40] propose an improved approach using a Parallel Tabu Search (PTS) method for distribution network planning in consideration of DG, reporting successful results in a sample system. In 2006 Domínguez et al. [41] propose a similar method, using conventional TS and considering optimal operation of DG. It is also noticed that considering a DG optimal operation, the generated power has increased 56.25% (comparing with the same optimization without optimal operation). In [41] the authors compare the results of the application of PTS with SA, GA and TS reporting not only less computational time, but also high robustness and reliability of the algorithm with a decrease of 55% on the expansion cost of the existing system.

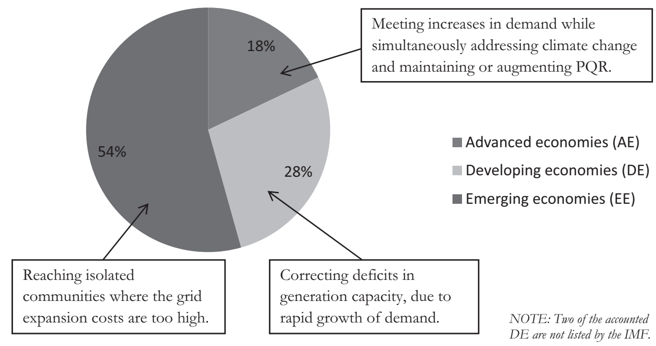

Fig. 2. The adoption of the microgrid concept makes sense at various levels. Expanding reach in developing economies; managing growth in rapid development economies; transforming growth in post-industrial economies. The classification of the World economies inherent to this figure is based on the International Monetary Fund (IMF) World Economy Outlook 2010 [50].

Still, GA is often used for solving the problem in the following years, through the work of Celli et al. [42], Haesen et al. [43], Carpinelli et al. [44], Santos et al. [45] and Borges and Falcão [46].

Until 2005–2006 most of the scrutinized studies (see [39–46]) preserve the fundamentally radial structure of the distribution grid, being DG optimally placed in certain interconnection points. From 2005 to 2006, a new generation of approaches have emerged, which are directed toward the development of networked microgrids with the capacity to operate in both grid-connected and islanded mode.

Microgrids are the ultimate form of decentralized electricity, heat and cold supply, whose operation can be totally separated from the main distribution system (autonomous) or connected to it (grid-connected). The operation of autonomous microgrids is particularly critical, due to the sensible control of voltage and frequency, although they possess the potential to reach remote non-electrified communities with social benefits [47,48]. In the other hand, a grid-connected microgrid could be helpful in case of system fault, providing the possibility of dispatching power to the main distribution system, feeding part of its loads during the operations for fault detection and service restoration. Combined with on-site production of heat, microgrids emerge in this challenging context as a competitive alternative to the final delivery of energy to consumers. Ribarov and Liscinsky [49] studied the viability of microgrids for small-scale cooling, heating, and power concluding that these systems have the potential to be economically feasible. DG grouped in microgrids have the potential to introduce a much richer set of tools for providing not only heat and power, but also increases in reliability, security, flexibility and power quality in the conventional grid. Fig. 2 shows the importance of microgrid introduction in both developed and fast emerging economies but also in developing countries. At the same time, this new trend bears the promise of environmental, economical and social cross-cut benefits for communities. In this context, the forthcoming shift from the current energy paradigm to the microgrid vision is almost certain while is also becoming an inspiring symbol of Sustainable Development.

As a result, a particular subset of contemporary research on DG, lies on the planning of microgrid systems, where design engineers are faced with the task of identifying the most appropriate generators and the most suitable location for them. Accordingly, the

microgrid concept focuses on the integration of multiple DG into the grid network, with several aspects concerning the grid reliability. In that sense many technical studies were issued in the last three to four years considering engineering optimization of microgrids.

The Instituto de Engenharia de Sistemas e Computadores do Porto (INESC Porto) has been one of the institutions exploring the technical implications of microgrid introduction in the current energy system. In 2005, Peças Lopes et al. [51] test a sequence of actions for microgrid service restoration through numerical simulations. Greater research efforts are put in the field by INESC in the years of 2008 and 2009, from which a number of studies are available. Madureira and Peças Lopes [52] present a metaheuristic optimization tool to address the voltage control problem of microgrids with large penetration of DG, enabling its use for online operation through the employment of Neural Networks. Costa et al. [53] propose a regulatory framework for the economic integration of microgrids on distribution networks. In addition, the role of Vehicle-to-Grid (V2G) as a driver for the penetration of intermittent renewables is studied by Peças Lopes et al. [54]. A number of other studies by INESC, mainly focusing on the technical, economical and emissions impact assessment of microgrid operation followed during 2009, such as the research pursued by Vasiljevska et al. [55] and Hatziargyriou et al. [56].

On the other hand, the task of microgrid planning is often a multi-faceted one. Design engineers are usually interested in addressing a number of different and often conflicting objectives for a particular microgrid, ranging from maximizing reliability to minimization of capital expenses or environmental burdens. In this process, microgrid structural units must be chosen and adequately quantified so that they can satisfy customer load demands in a technically feasible manner, being at the same time compromised with some pre-defined objectives. Solving the technical-environmental-economic problem in distributed generation planning has also received considerable attention during the last years. For that reason, these processes often make use of multiobjective optimization methods.

Berry et al. [57] reviewed in 2009 a set of multiobjective optimization approaches to decentralized planning. The author's main conclusion is that a significant part of the available studies fail to capitalize on the most contemporary multiobjective optimization theories, not taking into account recent advances in the domain where significant gains in both performance and analysis have been made. Instead, they have used dated methodologies both with respect to the algorithms exploited and the reported metrics used. At the same time, in [57], caution is recommended using classical a priori methods in microgrid planning, due to bias of the search towards areas of expected values, which may exclude potentially interesting solutions.

Mainly due to its inherent solution mechanisms, classical optimization techniques impose several limitations on solving operational research problems [58]. Solution strategies of classical optimization algorithms are generally dependent on the type of objective and constraint functions and the type of variables used for problem modeling. Furthermore, their efficiency is dependent on the size of the solution space, number of variables and constraints used in the problem modeling, and the structure of the solution space. In addition, classical optimization methods do not offer general solution strategies applicable to problem formulations where different type of variables, objective and constraint functions are utilized [58]. In the other hand heuristic optimization algorithms were proposed to overcome the drawbacks of the classical optimization procedures. These techniques, in some cases, have proved to be more efficient and certainly more flexible due to their capacity to be modified and adapted in order to suit specific problem requirements [58].

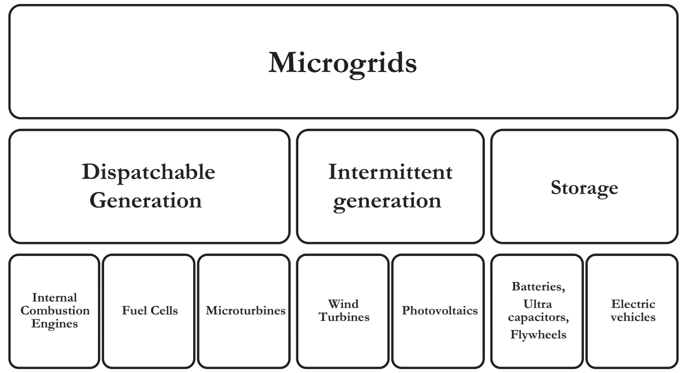

Fig. 3. Microgrids comprehend the whole concept of distributed generation, both dispatchable and intermittent coupled with advanced energy storage methods.

In general, [58] identified the following deficiencies in a sample of existing studies on multiobjective optimization approaches to microgrid planning:

1. The recurrent use of linear weighted sums, leading to inflexibility and non-identification of concave portions of the Pareto Front (PF);
2. Absent use of state-of-the-art Pareto-compliant performance analysis, not ensuring that results are representative of typical performance patterns and free of anomalies;
3. Use of outdated methods, not taking into consideration most of the powerful contemporary multiobjective techniques. All recent studies seem to suggest the accuracy of classical methods, although caution in problem formulation is advised in order to prevent unwanted bias of results. In general, most problems are more efficiently explored by means of approximate metaheuristic techniques, even though classical methods have been also successfully applied by many scientists in the DG sitting and sizing problem.

Taking benefit from the initial pioneer studies, multiple studies have followed through Mitra et al. [59], Mitra et al. [60], Krueasuk and Ongsakul [61–64] where PSO is used for solving the DG sitting and sizing problem, mostly applied to microgrid architectures.

Mitra et al. [65] utilizes a Dynamic Programming (DP) based method for designing microgrids optimized for cost and subject to reliability constraints, while taking into account the anticipated growth in the served region. Its method determines the optimal interconnection between DG and load points, given their locations and rights of way for possible interconnections. In 2006 Mitra et al. [66] uses the same method, introducing combined heat and power (CHP) to meet customer thermal loads.

Sporadically, other methods are tested to solve the problem. Vallem et al. [67] uses SA for the sitting of DG within the framework of an optimal microgrid architecture, minimizing deployment and heat compensation costs, subject to a minimum reliability level. In 2008, Rietz and Suryanarayanan [68] propose the Analytical Hierarchy Process (AHP) as a powerful decision-making tool for the design and operation of islanded microgrids. According to [68], AHP is adequate since it has been successfully applied in the field of design and operation of power systems. It takes advantage over other analytical methods on being able to incorporate subjective constraints.

Mixed Integer Programming (MIP) is commonly applicable to the DG and particularly microgrid planning problem due to the frequent combined use of both continuous and discrete variables, such as the type or number of DG. Surveyed studies often make use of Mixed Integer Linear techniques (MILP) or of Mixed Integer Non-Linear methods (MINLP). For instance in Casisi et al. [69] uses a MILP

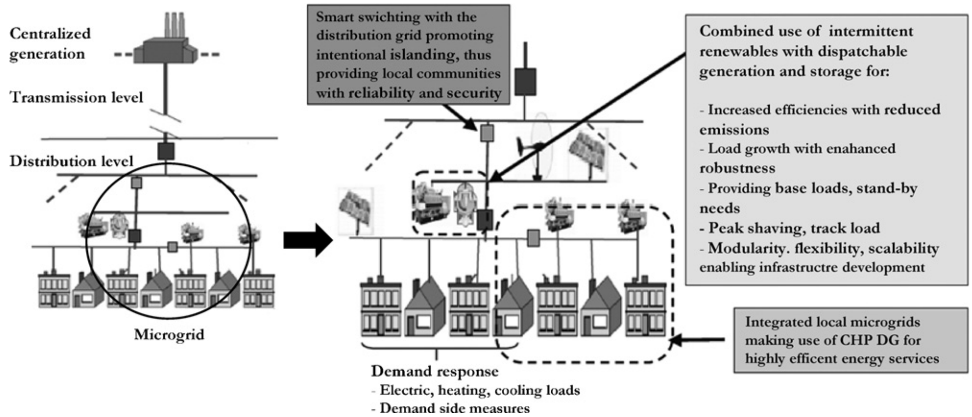

Fig. 4. Grid connection is on the basis not only of the increase in systems reliability and security through self sufficiency and intentional island but also of the potential economical benefits of the community and particularly of customers by selling electricity to the utility grid.
Adapted from [74].

algorithm for finding the optimal lay-out of a distributed urban cogeneration system and its optimal operation, in real-world conditions. The system is composed of a set of micro-gas turbines, located inside some public buildings, and a centralized cogeneration system based on an Internal Combustion Engine (ICE). Additionally, Ren and Gao [70] develop in 2010 a MILP model for the integrated plan and evaluation of DG systems, capable of minimizing the overall energy cost for a test year by selecting the units to install and determining their operating schedules, given the site's information on the available DG technologies, energy loads, climate data and utility tariffs.

An important body of the research on the field is being developed by the Microgrid group at the Lawrence Berkeley National Laboratory (LBNL), in California, USA, where a comprehensive number of published papers have significantly contributed to the development of the microgrid economical planning and analysis focus area. These studies have used the tool developed at LBNL DER-CAM which will be further analyzed. Kuri and Li [37] had already highlighted in 2004, the importance of the economical viability of DG introduction, particularly in the deregulated environment, advising also that due care is taken during the planning stage to ensure that system security and quality of supplies are not degraded.

The ultimate concept of the microgrid is basically an integrated system of distributed energy generation, both dispatchable and intermittent, coming from renewable sources and highly efficient cogeneration or trigeneration equipments, but also of energy storage and power loads working in parallel to or islanded from the utility power grid (see Fig. 3).

Potential applications of microgrids are diverse, which could be hospitals, residential neighborhoods, office parks, military bases and school campuses with their own distributed power, heat and cold generation sources. Many specialists forecast that microgrids will be a multi-gigawatt and multi-billion dollar market, although today this concept is still an emerging idea.

2.3. Integrated Community Energy Systems

ICES can be seen as a development of both the distributed generation and microgrid concepts. They correspond to a multifaceted approach for supplying a local community with its energy requirements from high-efficiency cogeneration or trigeneration energy sources and from renewable energy technologies, coupled with innovative energy storage solutions including the EV and energy efficiency demand-side measures. The biggest value of ICES is on the combination of different energy technologies, comprising generation from intermittent sources such as wind power, photovoltaics and solar thermal, base loads such as geothermal stations, dispatchable sources such as Internal Combustion Engines both diesel or gas-fired, fuel cells, microturbines and small gas engines. According to Chicco and Mancarella [3], only the commercialization of economically effective local generation technologies has enabled cogeneration to be profitable at a small scale, rather than on classical industrial applications. In that sense, it is widely acknowledged that nowadays a DG system based on small-scale cogeneration technologies can be advantageous when compared to an electricity-only system.

Current technologies available for heat and cooling can be conveniently heat or electricity-fired, thus allowing for a multitude of schemes for cogeneration. From the combined use of cogeneration equipments and Thermally Activated Technologies (TATs), such as absorption chillers arises the so-called trigeneration system. This kind of combined systems is characterized by excellent economical and environmental performances, adding also that feeding different technologies with varied fuels for producing different energy vectors gives origin to a multitude of alternatives for more effective design and planning of energy systems [3].

IES is bringing together advanced technologies that will supply communities with its full energy requirements via islanded but essentially grid connected microgrids. Grid connection is on the basis not only of the increase in systems reliability and security through self sufficiency and intentional island but also of the potential economical benefits of the community and particularly of customers by selling electricity to the utility grid (see Fig. 4). In this context, the existence of adequate regulation is of major importance. For instance in the case of Portugal, microgeneration legal framework was established in 2007 through DL no. 363/2007, allowing for selling electricity to the main utility with attractive tariffs. Presently, the regulator entity announced so far nearly 10.6 MW of completed applications in 2010 adding to the 13.7 MW of 2009, the 10.8 MW of 2008. However, as in most countries, this regulation generally fits on IP but not specifically to the microgrid regime. Also, the framework was particularly designed for promoting micro renewables. In the case of ICES, specific legislation is needed aggressively promoting the integration of energy systems and taking into account the role of the community in exchanging electricity to the main utility and not solely the independent micro producer. Regulatory environment has already been pointed by some authors as one of the main barriers of microgrid infrastructure development. Pudjianto et al. [71], Venkataramanan and Marnay [72] and Marnay et al. [73] all consider that market mechanisms are still not mature enough to accommodate the

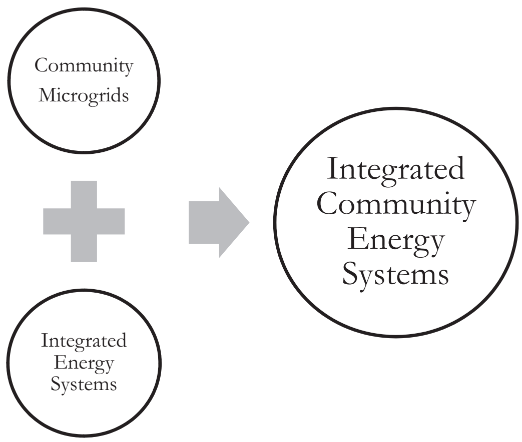

Fig. 5. ICES are a combination of the Integrated Energy Systems concept with community microgrids vision, bearing the potential for developing highly robust energy systems, by providing significant reliability and security benefits.

introduction of microgrid entities. Additionally, the regulatory environment into which microgrids are entering is extremely complex, as they involve multiple areas of existing regulation not initially conceiving them, such as generator interconnection rules, air quality permitting, building codes and tariff application [73].

ICES can offer the option for communities to be self sufficient, stand alone, energy efficient, with or without grid connection and using diverse fuels, being them renewable or not, like natural gas and oil. Further developments can take communities to use the residues of their own activities for energy production such as in the case solid biofuels use like wood, grass cuttings and domestic refuse, with significantly less impact on the environment than fossil based fuels.

Furthermore, coupling the Integrated Energy Systems concept with microgrid vision, there is the potential for developing highly robust and secure community and neighborhood-based microgrids, leading to hardened energy systems by providing significant reliability and security benefits [75] (see Fig. 5). ICES will work as energy generation islands that are linked via one point to the electricity system, largely bypassing the conventional grid to cut transmission and distribution losses and charges. At the same time, avoiding the transmission and distribution infrastructure development is one way to avoid NIMBY opposition phenomenons.

Following the approach of Systems Thinking, there is the potential for having multiple microgrids working in conjunction, resulting in wider benefits. The surplus from one generating island can be used to make up the deficit at another, thus increasing the robustness and global energy security of the entire energy system.

Integrated Energy Systems are community investments. There is a number of good reasons for favoring local investments, such as, for instance:

- Sharing of the generated benefits coming from DGs more equally, than when large investors are involved: Local investment allows a better share of wealth, opening the door to a clear appropriation of the project by local inhabitants.
- Support economical development in rural areas: the involvement of local actors in the destiny of their territories is a key factor for the development of local communities, especially in remote and rural areas. In regions where agriculture or traditional industries are declining, ICES projects offer an opportunity to diversify economic activities.
- Improve local acceptance of specially renewable energy projects: Some projects face local opposition, particularly wind energy which unavoidably modifies the landscape. This is aggravated by the common perception that there are no local benefits associated with these impacts on communities, generating NIMBY phenomenons. In the case of ICES, associated with a comprehensive and sensitive information campaign, local investment is likely to reduce the risk of a strong opposition by allocating more benefits to those people who potentially endure the drawbacks.
- Play an educational role: Due to the centralized traditional paradigm of energy production, nowadays extended to renewable energy generation, a big part of the populations is not fully aware of the importance and values associated to clean energy projects. For instance in Portugal, Fonseca [76] highlights that 64% of the population is not informed of any developments on the field of energy efficiency in the country and the same applies to renewable energy, where the percentage grows to 67%. Compliance of the numerous political commitments at both European and national levels implies the direct involvement and needs a strong support from public community. Local investment can play a significant educational role by increasing the number of people directly and indirectly involved in effective projects, and thus the public awareness on clean energy. By creating social links in the framework of a local project, it can also promote the emergence of new local projects through exchanges about the initial one.

Additionally, ICES must go beyond the unidirectional infrastructure-based system to include the long-term community response component. In that sense, Demand Side Management is vital. Energy demand management activities, entailing actions influencing the quantity or patterns of energy use by consumers, should bring the demand and supply closer to a perceived optimum.

Finally, the concept of ICES is hoped to provide strong ideological and aesthetic meaning to communities in general, who recognize a common value system in which a greater dependence on highly efficient and cleaner energy systems is demanded by current World context [75]. Adding to this, other social benefits may arise from the implementation of ICES, namely local employment enhancement and community social cohesion and development [77]. In cases of remote communities, electrification of isolated areas can also be considered a positive effect of ICES introduction. It is noticeable though, that an investigation on the social aspects of these systems, as in any other energy related issues, must be made along with the examination of its economical and environmental aspects. This is due to the tight interconnection of social benefits with the economical and environmental perspectives, being often hard to distinguish between them.

Microgrid planning is still embryonic, especially when it comes to designing Integrated Energy Systems. Most of current work is related with renewable hybrid energy systems design, only able to provide electricity needs and normally applied to remote communities. For that purpose, HOMER, which will be overview in Section 4.1 has been the most utilized energy modeling tool. Still, a few dispersed studies have been pioneering integrated community-level microgrid design. For instance, Agalgaonkar et al. [78] had utilized EADER (which will be further explored in Section 4.1) for performing economically optimal sizing of distributed generators in a microgrid located in Western Maharashtra, India. Model output represent an integrated system composed of 2.40 MW of natural gas-fired generators, 0.50 MW of biomass based generators and 14.25 kW of wind turbine generators. Pelet et al. [79] had utilized a multiobjective evolutionary optimization algorithm to rationalize the design of energy integrated systems for remote (isolated) communities considering total costs and CO_2 emissions. A range of technology options were considered such as diesel engines including CHP, photovoltaics, heat storage, cooling towers or solar parabolic trough collectors. The results of the case study of an

isolated oasis show that although allowing for significant CO_2 emission reduction, solutions including solar power production either from thermal or photovoltaic conversion units were not economically viable, even in extremely favorable solar conditions.

Modeling tools such as DER-CAM and others have been mainly utilized for pioneering this field of study. An overall approach on viable tools applicable to the sustainable planning of ICES will be done in Section 4.

3. Systems Thinking applied to the design of Integrated Community Energy Systems

The approach of ICES follows principles related to Systems Thinking, in which a system is an organized collection of subsystems that are highly integrated to accomplish an overall goal, bigger than its independent ones. Scientists use systems theory to understand how things work. Systems theory suggests that one models natural or human-made phenomena as a set of interrelated components that work together to accomplish some kind of process.

There is two ways in which the design and implementation of ICES follows Systems Thinking:

1. Addressing global problems such as Climate Change or Poverty by implementing sustainable energy communities is thinking in systems, that is to be certain a greater good will be achieved by acting locally;
2. ICES are themselves composed of a combination of multi-fired technologies, being integrated approaches of energy delivery to consumers.

In a system all the functions are interdependent. If any function fails then the whole is affected. Energy Systems in whatever scale one considers, can also achieve greater results by working in an integrated manner. One must consider the integration of the different energy subsystems and their contribution to the overall system efficiency, the characterization and optimization of the Integrated Energy System. In fact, building a successful Integrated Energy System is a *design problem*.

Additionally, designing Integrated Energy Systems is what can be called a Hard Problem. A hard problem is usually a real-world problem, which can be formulated as the search for an efficient means of achieving a defined end. Hard Systems Thinking is an approach to real-world problems in which an objective or end-to-be-achieved can be taken as given. Then, to meet or achieve the objective, a system is engineered. Hard Systems Thinking makes use of the kind of thinking which is natural to design engineers. The role of a design engineer is considered to be to provide an efficient way of meeting a defined need, working in a situation where what is required has been defined, being his job is to examine how it can be provided. This is typically a work of finding and providing answers to the question: How?

For the hard system thinkers a system is typically a machine with a function. To understand the system, one has to decompose it into smaller parts, and then, study the functions of these parts. By asking the question: What does this thing do, we reduce the complexity and focus on the functionality of the given thing. This way of thinking, is necessary in order to understand the world according to the hard system thinkers.

What is in reality, the design problem explored in this paper? The main objective is to minimize the economical and environmental (and consequently social) cost of operating on-site distributed generation equipment, for a community level integrated energy microgrid. Consequently this leads one to three specific questions, which are:

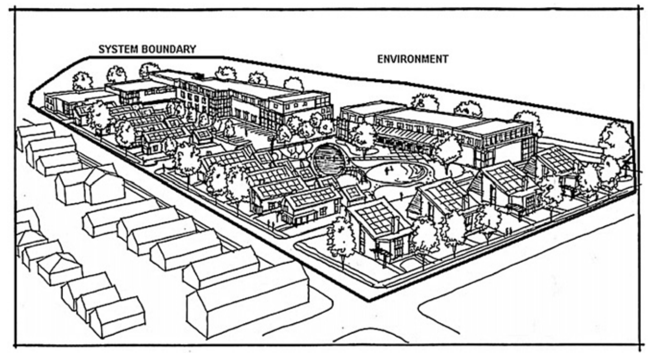

Fig. 6. Generic representation of an Integrated Community Energy System, in terms of Systems Thinking.
Adapted from [80].

- What is the appropriate combination of technologies to apply?
- What is the adequate power capacity for each selected technology?
- What is the best operation period for each one of the technologies?

In this case, for representing a real-world human-made problem a model will be used/expanded. Models have functional relationships, being involved inputs and outputs, such as systems. The fact that functional relationships exist between the parts suggests the flow and transfer of (in this case) energy. In Engineering, a system is the physical portion of the universe that is being studied. In our case, the system is man-made (or a designed) system, an integrated energy microgrid, able to function isolated or grid-connected. The physical limits of the neighborhood buildings represent the system's boundary. As this is a system able to deliver energy to the macrogrid, but not matter, it can be in theory considered a closed system (Fig. 6).

The objective of the designed system is to provide electrical and thermal energy to the community inhabitants and additionally to sell it to the macrogrid. However, its several structural subsystems have many other functions which on the whole lead to the primary aim of this infrastructure. A group of main subsystems operating within the microgrid can easily be defined: Basically, the equipments within the system are present to satisfy five different types of end uses: Electricity only, building cooling, building heating, hot water and gas only.

Within the boundary of a system, three kinds of properties can be found:

- Elements – are the kinds of parts (things or substances) that make up a system.
- Attributes – are characteristics of the elements that may be perceived and measured.
- Relationships – are the associations that occur between elements and attributes. These associations are based on cause and effect.

The state of the system can thus be defined by determining the value of its properties (the elements, attributes, and/or relationships). The design exercise explained here consists exactly on defining the state of a studied system. This means answering the questions "Which elements?", "How much of each one?" and "When to use them?". One static, bottom-up model can do such work.

4. Survey of available energy models for Integrated Community Energy Systems planning and analysis

The next chapter will give an overview on the few existing tools, which can potentially be used for the planning and analysis of IES at the community/village level, specifically able or easily adaptable to model microgrid systems. In terms of scale, this is the bottom limit of the application of the decentralized planning principle. In some aspects, the survey follows the classification methodology presented by Connolly et al. [5] and Mancarella [3].

Before starting, it might be important to define some of the aspects which serve as criteria and are analyzed further in detail:

- A *bottom-up tool* identifies and analyses specific energy technologies, finding investment options and alternatives. In this study, there is a particular interest in identifying bottom-up models;
- A *simulation tool* basically simulates the operation of an energy system supplying the correspondent energy demand needs;
- *Scenario tools* usually combine series of annual results into long-term scenarios, of typically 20 to 50 years;
- An *equilibrium tool* explains the behavior of supply, demand and prices, normally in the whole or in part of an economy, with several or many markets;
- An *operation optimization tool* optimizes the operation of some given energy system. It is common that operation optimization tools are also simulation tools, simulating the operation of the same system for attaining optimal results;
- An *investment optimization tool* optimizes investments in an energy system in study. Typically, optimization tools are also scenario tools.

The selection of the surveyed models was highly dependent on its availability. Only MARKAL/TIMES and in some extent DER-CAM are commercially available models. EAM capabilities were explored through the various available publications. H_2RES is well known by the authors, as it is developed at IST-UTL. The remaining tools are freely available over the Internet. At the same time, few additional viable tools were identified for the purpose of this study.

4.1. HOMER

The Hybrid Optimization Model for Electric Renewables (HOMER) was developed in 1993 by the North-American National Renewable Energy Laboratory (NREL). HOMER is able to perform analyses in either grid-connected or off-grid environments, in order to explore and respond the following questions [81]:

1. Which are most cost-effective technologies to apply in a given system (under a pre-selected set of technologies)?
2. What is the appropriate size of the components to install?
3. What happens to the project's economics, in a scenario of variable costs and loads?
4. Is the renewable resource the adequate one?

For answering these questions HOMER finds the least cost combination of components that meet electrical and thermal loads of an energy system, by simulating thousands of system configurations and optimizing for lifecycle cost. One of the good features of HOMER is that it is able to perform additional sensitivity analyses on most inputs, which can help the user investigating the effect of changes in input variables, providing a functionality which is not found in any of the other surveyed models. Probably due to its free distribution policy and user-friendly interface, HOMER is one of the most popular microgeneration evaluation tools on the market, being used worldwide for numerous scientific and industry projects. The model also supports a diverse set of technologies for electricity, heat and cooling generation, including CHP, Trigeneration and storage, such as conventional generators, wind turbines, solar photovoltaics, hydropower, batteries, fuel cells, hydropower, biomass and others. HOMER simulates the operation of a system by making energy balance calculations on an hourly basis, minimizing what its developers call the "lifecycle cost", which accounts for the capital, replacement, operation and maintenance, fuel and interest costs of the system. Thus, investment and operation optimization is done. In the end, the interface provides the user a group of valuable graphics which enrich the final analysis of the system.

Most applications of this model have been on the electrification of remote locations, especially in third-world countries, where the integration of renewable energies is most desirable. Although current capacities of HOMER software allow for modeling community-level IES, no studies have been found regarding this issue. However, there is potential for the analysis of microgrid-based IES with HOMER, mainly because IES have been modeled already for single-residential systems [82]. Also, there is a number of publications regarding fuel cell implementation for power-only operation. Within these publications a typical New Zealand rural community consisting of three adjacent farms [83] and a small village in the US [84] are worth mentioning examples.

In 2006, Agalgaonkar et al. [78] presents the Economic Analyzer for Distributed Energy Resources – EADER as an improvement of HOMER model with significant advantages over the latter, regarding the economic analysis of microgrids of heat and power. The author conceives that the concept of microgrid supersedes all the advantages of single source and hybrid DG and thus the advantages of networking at mini scale must be taken into account. The microgrid concept, as it involves small transmission and distribution network, efficiently makes use of all location specific DGs, lowering costs. In fact, Agalgaonkar et al. adopts the microgrid concept developed by Peças Lopes et al. [51] in 2005, in which the overall operation of the microgrid is controlled by three controllers: (1) The Microgrid Central Controller (MGCC), (2) the Microsource Controller (MC) and (3) the Load Controller (LC). Thus, according to [78], EADER has the following features:

- Fuel used in a year is more accurately calculated by taking into account Power to Heat ratio, Heat recovery ratio, and efficiency of the DG;
- Any number of wind turbine and fuel powered generators can be simulated;
- Operation and maintenance cost becomes modeled as function of the generated electrical energy, making it more accurately calculated;
- Transmission line and transformers can are modeled in EADER;
- Controller costs, overhead charges, contingency amount, taxes and insurances are taken explicitly into account.

For model validation, Agalgaonkar et al. [78] performs a comparative analysis in an example system, in which the novel tool ends up yielding very close results compared to HOMER. Finally, EADER results for a tested microgrid system in Western Maharashtra, India, show a slight increase in cost of energy as compared to single source DG and hybrid DG which according to the author can be justified by increased reliability and self-sufficiency. The author indicates also the limitations and assumptions to consider for future model improvement such as non-consideration of a number of DG and no computation of emissions.

Although EADER development efforts are seriously worth mentioning, it is noticed that it is a tool which is still under development and improvement by its authors. Additionally, this study looks for mature and stabilized models. In this sense, for the purpose of this survey the author decided not to include this model in further comparisons.

Another NREL software tool is the Village Power Optimization for Renewables (ViPOR) model, whose objective is the design of community-level microgrids. ViPOR optimally designs the distribution grid till the village level. Whenever the model chooses best, it may isolate one system, forming off-grid communities and designing its optimal configuration. Comparing to the other surveyed models, ViPOR is unique in one sense; its SA algorithm takes into account the spatial location of inputs. For instance, ViPOR minimizes river or forest crossings and elevated areas, while maximizing road following, in order to reduce infrastructure costs. In this way, ViPOR inputs are divided into spatial and non-spatial. Geographic description of a village is needed. The model has its own interface for enabling local geographic description, also being possible the import of GIS and GPS-based data. ViPOR considers also an extensive list of non-spatial inputs, such as location and requirements of each expected load and wire and transformer costs.

According to NREL, ViPOR works integrated with HOMER. Namely, the economical component of DG and centralized systems is computed for a range of load sizes with the aid of HOMER. As the model searches for the optimal local system configuration, it may consider many different sizes of DG systems, using generation cost curves to calculate the costs associated with each.

It is noticed that ViPOR has been mainly used for internal NREL projects, such as the Chiloe Islands Case Study, in Southern Chile. Additionally, ViPor is worth mentioning due to some of its particular capabilities for modeling community-level microgrids, however this tool models only electrical systems omitting thermal loads and for that reason it won't be further compared with the other models.

4.2. DER-CAM

LBNL researchers have developed the Distributed Energy Resources Customer Adoption Model (DER-CAM) [85–88], an economic model capable of finding the best possible combinations of DG technologies, its optimal capacity and operation profile that meet a microgrid's both electrical and thermal loads. The optimization is done a priori, for given utility tariffs, fuel cost and other equipment data. DER-CAM is a General Algebraic Modeling System (GAMS) based (using the CPLEX solver – a combination of the Simplex Method and the Branch and Bound one) Mixed Integer Linear Programming (MILP) model. DER-CAM has mainly been used for three different types of applications:

1. Primarily, it can be utilized to guide choices of equipment adoption at specific sites, or provide general solutions for hypothetical sites and compare good quality choices for similar sites;
2. It provides a reliable basis for the operations of installed on-site DG;
3. It can be used to assess the market potential of technologies, by anticipating which kinds of customers might find various technologies attractive. Its adaptability and ease of utilization have been imperative for its use in a number of published works by LBNL in which this model has paved the way for many advances in the field regarding the economical and in a certain extent the environmental feasibility of microgrids.

Siddiqui et al. [89] first use a GAMS-based version of DER-CAM in 2001, for the assessment of the impact of a carbon tax and resulting carbon emissions on DG adoption by a microgrid. It is found that increases in the carbon tax stimulate DG adoption and that more carbon abatement is possible at lower tax levels DG technologies are granted subsidies towards their turnkey costs [89]. In 2002 Bailey et al. [90] analyze the potential for pairing CHP with on-site electricity generation to provide power, heating and cooling services to customers. To analyze the cost effectiveness of this possibility, DER-CAM was expanded to include microgrid thermal systems thus determining the optimal least-cost combination of technologies to provide a microgrid's power, heating and cooling needs [90].

Also in 2002 a reference publication from Edwards et al. [91] was released. For the first time, the use of DER-CAM is combined with GIS for the assessment of the local potential for deployment of DG. The basis of this work lays on the fact that although local constraints that may inhibit or prevent installation of economically attractive DG technologies are well-known frustrations in the field of DG planning, no analysis method had been at the time developed to address those issues. Some examples of local constraints are noise and air quality limits, restrictions on crossing public rights-of-way, the density of buildings and availability of open space to install a generator, physical limitations on the transfer of generator waste heat and access to high-pressure natural gas lines. By incorporating established DG planning and evaluation techniques with a GIS, local spatial constraints on DG can be readily addressed and analyzed [91]. However, the ability of GIS to accurately analyze land-use constraints is still limited. This is primarily because of the limitations on publicly available GIS data, which are collected and shared mainly for the purpose of conducting geographic analyses on a city-wide or larger scale, i.e. to reflect variation among neighborhoods, but not within them. San Diego, this work's case study, has collected and made publicly available GIS data for land-use patterns, roads, climate variation, environmentally sensitive areas, and other information relevant to a local analysis of DG deployment (SanGIS). Individual buildings data from SanGIS identify property limits by the building owner although it does not distinguish individual tenants within commercial sites or another number of possible details within a single property. Consequently, in this case, as in many others, some general assumptions regarding the buildings must be made. The results achieved by Edwards et al. [91] are very interesting and certainly add profoundness to the traditional result reports of DG analysis from DER-CAM. Results describe the optimal sites for the technologies chosen on an economical basis by DER-CAM and reveal some of the inherent difficulties or possible advantages DG might encounter as a result of local land-use patterns. The GIS analysis process demonstrates that certain technologies might have to be eliminated from consideration, based on overall noise restrictions, and that other technologies would be suitable if additional requirements, such as heat-transfer upgrades, were met. Edwards et al. [91] conclude considering that it is worthwhile to take geographic constraints into account at this stage of development of DG planning, and to evaluate methods of assessing them. With the compilation of more complete databases of small-scale land-use information, GIS may prove to be an important tool in the analysis of DG technology potential [91]. Although promising, the symbiosis of DER-CAM and GIS was not identified in any other surveyed study. In 2003 Siddiqui et al. [92] tests the incorporation of CHP technology in a cluster of businesses and residences in a San Diego neighborhood, assumed to be operating as an Integrated Energy System. Under a number of idealized assumptions, results show a significant increase in savings (about 10%) when CHP technology is selected instead of conventional DG [92]. The addition of CHP to DER-CAM is considered by LBNL a tremendous step towards creating a realistic customer adoption model. This is easily justified by the simple fact, confirmed also in [92], that the recovered waste heat from DG has a significant value and often tips the scales in favor of DG over the main grid dependence. Bailey et al. [93] offered the first opportunity to apply DER-CAM in a real-world setting and evaluate its modeling results. Scenarios were modeled to show the options and financial value of different energy system designs, while the modeling results emphasized the importance of DG grants and included sensitivity analyses on important parameters such as the spark-spread rate, standby charges, and general tariff structures. The work presented in [93], despite the fact that

in this study the microgrid form was not considered, helped in the maturation of DER-CAM: the financial estimates and technology adoption decisions were validated, the accuracy of the model was improved and its capabilities were expanded based on real-world experience. In 2004, Firestone and Marnay [94] publish a reference paper on the design of the Energy Manager (EM) for the control of microgrid equipment. Microgrids require control to guarantee safe operation of the system and also to attain dispatch decisions that achieve cost minimization, reliability, efficiency and environmental requirements, while subject to technical and regulatory constraints [94]. Efficient EMs have above all the capability to minimize system operation costs, making microgrids attractive to the largest possible range of customers and ensuring that existing microgrids extract their maximum potential benefits [94]. A follow up of this introductory work was later issued by Firestone et al. [95], where a new algorithm for the real-time dispatch optimization problem for a generic Integrated Energy System (IES), containing an on-site cogeneration system subject to random outages, limited curtailment opportunities, an intermittent renewable electricity source and thermal storage is proposed.

LBNL continues its work on the evaluation of the economics of microgrids in the year of 2006. Energy and Division [96] adapts DER-CAM to the Japan settings on energy tariffs, DG costs and performance characteristics and building power profiles, being born E-GAMS. The expanded model is used to find the optimal combination and operation of DG to minimize the energy bills in an Eco-Campus of Japan. In 2007, Marnay et al. [97] extends DER-CAM to incorporate electrical storage options and for finding the most economically attractive combination of both equipment and its operation over a typical year, for a prototypical microgrid in the San Francisco area. The objective of this work was to demonstrate the new capabilities of the model. Introduction of electrical storage into DER-CAM enables an improved analysis of the emerging transportation technologies, such as the adoption of plug-in hybrids, with their on-board electrical storage capabilities. Possible services emerging from the integration of such technologies into the electrical infrastructure of buildings may as well make its economics more attractive and accelerate their deployment [97].

In 2009, Stadler et al. [98] examined how Zero Net-Energy Buildings (ZNEB) may be implemented within the context of a cost and CO_2 minimizing microgrid in northern California, able to adopt and operate a group of DG technologies, as well as Demand Side Management (DSM) measures. This work represents a significant step forward in DER-CAM functioning, taking into account the introduction of a second environmental objective in the algorithm and DSM capabilities, which will enable entities to reduce both electricity and heat consumption via demand-side energy efficiency measures, for a certain number of hours each year. In the studied case, the energy bill soars due to the adoption of costly equipment, although US subsidies on renewable energy and storage technologies could make ZNEB attainable at a modest increase in the energy bill. Also, there is a trade-off between cost and CO_2 emissions, while zero-carbon status could only be achieved at a quick increase in the energy bill. The use of DSM is assumed to have a vital importance in this context, since without it, the reduction in CO_2 emissions that are attained via a combination of renewable power and electrical storage, would be prohibitively expensive [98]. Stadler et al. work on greenhouse gas abatement continued in [99] and [100] where the authors find the greenhouse gas reduction potential for California's commercial sector, through the use of DG with CHP, within the context of a cost minimizing microgrid.

In a more recent research in 2010, Momber et al. [101] performs an Economic analysis to the Plug-in Electric Vehicle (PEV) interactions with a commercial site, using DER-CAM. It is generally recognized that PEV's, compared to conventional vehicles, offer environmental and energy security advantages that may facilitate the deployment of DG and make available ancillary services for maintaining the balance between electricity load and generation [101]. Technically speaking, DER-CAM capabilities do not need to be improved in order to support PEV introduction. In fact, the electric vehicle may well be perceived simply as an electrical storage option, which already existed in the model (see [97]). It is found that cost reductions from stationary batteries or PEV connections are modest, although results show that some economic benefit is created due to avoidance of demand charges and tariffs.

DER-CAM limitations have been clearly identified by its authors; To begin with, outputs and efficiencies are considered as constant during the lifetime of equipments and start-up or other ramping constraints are not included. This means the model does not consider scale economies of equipments. This line of thought applies also for reliability and power quality benefits, as well as economies of scale in O&M costs for multiple units of the same technology, which are not directly taken into account. Furthermore, DER-CAM does not internalize potential reliability or power quality improvements in the system.

4.3. EAM

A similar tool to DER-CAM is being developed in Japan by the work team composed of Asano, Bando, and Watanabe. This tool, also written on GAMS, is not clearly identified in the work that has been surveyed, thus it will be further named as EAM – Economic Evaluation of Microgrids. In 2006 [102], reporting the non-cost-effectiveness of the New Energy and Industrial Technology Development Organization (NEDO) Aichi, Hachinohe and Kyoto Fuel Cell (FC), Photovoltaics (PV) and Wind Turbine (WT) based pilot projects, Asano and Bando proposes a hybrid microgrid system able to compensate whatever load variations such a system may have to deal with (intermittent renewable output and fluctuating demand), based on a controllable prime mover (in this case, Gas Engines – GE) and PV [102]. A load profile analysis for an office and residential buildings was done in order to better understand the trends of daily load curves, periodograms and residual demand. Examination revealed the appropriate time length for operational planning of the hybrid generation system. DG operation optimization was performed, indicating that the proposed operation method is effective for energy-efficient operation of microgrids [102]. In the subsequent year, Asano and Watanabe [103] proposes a methodology for the sizing of microgrid systems, in respect to the type and number of equipment units and correspondent power capacity. The objective of the approach is to attain the minimization of the annual cost of supplying electricity, while choosing the optimal DG operation schedule. In opposition to DER-CAM, the problem is described here as Mixed Integer Non-Linear Programming (MINLP) model, because a non-linear consumption of fuel is considered. The formulated problem is also solved using the GAMS package. Asano and Bando continued their work releasing in 2007 [104] and in 2008 [105] publications where the economical evaluation of microgrids assumes a more serious and definitive shape. The objective of this work is to answer the subsequent three basic questions related to the economics of microgrids:

1. What should be the appropriate size of a microgrid for it to become economically viable?
2. How much percent of capacity of PV or WT is adequate for a microgrid with constraints of power quality?
3. How much extra money do costumers pay for microgrid “green” power?

To draw conclusions on these questions, Asano and Bando in [104] utilize the model presented in [102] to solve the problem for a building complex (office +residential) case-study. The authors

perform a forced investment in the CHP GE technology due to their conviction that this equipment is adequate for the power output adjustment from intermittent renewable energy sources such as PV (which is consistent with [102]). Besides the generators, Asano and Bando's methodology takes into account storage from batteries and thermal tanks, although these equipments were excluded from the algorithm in [104], due to high initial costs. The authors conclude on the robustness of their methodology for cost minimizing design and operation of microgrids, which they believe is capable of fostering the services of smaller loads with cleaner, more efficient and more reliable technologies. In a similar work, Asano et al. [105] performs structural optimization of a microgrid allowing for CHP. In this case, though, the nonlinear partial load efficiency of a GE and its scale economy are introduced in the model. The established method of Asano et al. leads to an optimal number and capacity of pieces of equipment and annual operation schedule of a microgrid. In addition, a thermal storage tank for space cooling and heating is economically selected, for minimizing the need of auxiliary equipment, such as an absorption chiller.

4.4. MARKAL/TIMES

The Market Allocation model (MARKAL) and The Integrated MARKAL/EFOM System (TIMES) represent one of the most widely utilized Integrated Energy Systems modeling platform in energy Industry and Academia. MARKAL/TIMES can be tailored to analyze energy, economic and environmental issues at the global, national and municipal level over several decades [107]. These tools have been developed over the past several years in a collaborative effort under the auspices of the Energy Technologies Systems Analysis Programme (ETSAP), along with VEDA and ANSWER, the complementary interfaces needed for the system's data management. The problem that MARKAL/TIMES tries to solve is a MILP, and the commercial solver which runs it is the CPLEX/GAMS package.

Furthermore, MARKAL/TIMES is a highly detailed general purpose model, which is able to represent any user-defined energy-environment system, representing its evolution over a period up to 50 years. The time step used in this economic equilibrium model can vary according to user purpose, but its maximum resolution is hourly basis. The model supports a wide range of energy generation technologies, renewable, conventional, storage and also transportation which is also customizable. The characteristics of each technology include investment, operating and maintenance costs, service life, efficiency, availability and emissions. MARKAL/TIMES is a full-sector model, meaning that it comprehends energy generation but also fuel production located upstream in the energy chain and all forms of energy consumption in all demand sectors of an economy. The MARKAL/TIMES model is particularly effective in identifying the least-cost mix of energy carriers and existing new technologies that will satisfy the energy service demands and meet all the constraints imposed on the energy system. That is, MARKAL/TIMES performs Investment Optimization. Additionally, the TIMES Climate Module allows for detailed analysis of Climate Change effects such as green house gases emissions, changes in atmospheric temperature and radioactive forcing.

MARKAL/TIMES is also a Scenario evaluation tool. A series of Policy scenarios can be investigated with the model to explore their impact in comparison to a predefined Reference scenario. Policy scenarios that can be analyzed with the model include measures to cut emissions and promote energy efficiency, to improve energy security or to reduce new technology costs.

In 2005, Howells et al. [107] utilized TIMES for the modeling of household energy services in a low-income rural isolated African village. The main objective of this study was to find the least-cost method for meeting the thermal and electricity energy needs of the village, being for instance given special attention to the indoor air pollution issues, related to the fuel use. A scenario analysis is performed being explored a number of alternative frameworks which consider for instance grid electrification or not and, the variation of electricity prices and the health effects of indoor air pollution. For this modeling, Howells et al. increased the time resolution of the model to reflect daily load curves. According to the author, using a higher time slice resolution allows for more careful estimation of peak system requirements and also allows for better modeling of the possible effects of demand-side management programs. The work of Howells et al. in exploring rural community-level energy modeling using MARKAL/TIMES [107–109] is well-known, however as Hiremath et al. [4] also concluded in 2007, village-level decentralized planning approaches are rather limited, focusing mainly on broader rural areas such as clusters of villages or districts, instead of individual communities. In [109] Alfstad et al. explains a number of issues concerning rural areas which enlighten the importance of village-level energy planning. Additionally, studies of MARKAL/TIMES application exploring the concept of IES and analyzing the long-term evolution of a mix of RE and cogeneration technologies for the community, were not identified by the authors. Nevertheless, according to [110] the capabilities of this tool to model cogeneration community energy systems was explored in a study performed in 1998 by Canadian authorities, related to adoption of measures for Climate Change strategy. These studies are not available which also confirms that it is possible that in a number of occasions, applications exist of MARKAL/TIMES model for governments, states or municipalities authorities which have been done, but are not available for the scientific community.

4.5. RETScreen

Another potentially interesting tool for the planning of IES is RETScreen Clean Energy Project Analysis Software. RETScreen is a decision support tool jointly developed by the Government, Industry and Academia by Natural Resources Canada in 1996. It is freely available for download from the website of RETScreen International. According to the survey employed by Connoly et al., approximately 1000 people download the tool every week. RETScreen supports a number of CHP and trigeneration technologies such as absorption chillers, gas turbines, reciprocating engines and fuel cells and community IES modeling trough the Combined Heat & Power Model. It is able to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for both isolated and grid-connected cogeneration projects. In terms of scale, the tool has the capabilities to analyze a variety of projects ranging in size, as for instance natural gas-fired gas turbine connected to district energy networks, biomass-fired distributed energy systems providing cooling, heating and power to institutional and commercial buildings and industrial facilities or small-scale remote reciprocating engine CHP systems. On the extent of IES, RETScreen allows for parallel use and analysis of a wide range of renewable and conventional technologies.

RETScreen is a scenario tool, performing comparisons between the conventional case and an alternate "clean energy" one, aided by economical indicators such as the NPV and IRR of the investment. The output of this simple approach is that in the end the investment costs are optimized very quickly, also because RETScreen uses monthly time steps. Some advantages of this model are that it allows for a multiple number of generators, its ease of use and user-friendly interface. One limitation which is known from the model is its inability to model any storage systems but batteries.

RETScreen has been mainly used for two particular kinds of applications: Various scale renewable energy project analysis and large capacity plant design. There are a number of case studies regarding the modeling of CHP and trigeneration facilities, but not

of IES. For instance in 1996 [111] the Honeywell Farms dairy processing facility achieved significant energy and cost-saving goals trough modeling the retrofit of a cogeneration for a trigeneration system. To reach these goals, measures such as using cogeneration concepts for refrigeration prime movers, the waste energy recovery using absorption refrigeration for subcooling and exhaust heat recovery for steam generation. Electrical energy demand reduced over 50% while the overall Coefficient of Performance increased by 6%. In 2000 [112], RETScreen supported the project of a heat pump-based supply linked to a water-cooled refrigeration system, for meeting a Walmart complex's all-season HVAC needs. The company estimated comparative energy savings of 22% (1.15 million kWh/year).

Also, RETScreen has been used for CHP and trigeneration project planning of multi-residential communities: In 2002 [113], RETScreen was used for planning the New Jersey's Summit Plaza residential towers system. It is a trigeneration application composed of five diesel engines, two absorption chillers and hot water hydronic heating. The Summit Plaza unit provides power, heating, and cooling to four residential towers, a local public grade school with a heated pool, trash collection and a commercial property. Although completely autonomous, for energy security reasons this system is currently connected to the main grid. Also in 2000, RETScreen contributed to the examination of the environmental benefits associated with the upgrading of an existing District Heating and Cooling (DHC) plant at California State University complex, Fullerton [114]. Upgrading of DHC system incorporated both energy efficient technologies and modern operational concepts such as hot water and chilled water variable distribution, replacement of absorption chillers by more efficient electric motor driven centrifugal chillers and incorporation of a new heat recovery chiller, with substantial energy savings for the multiple building complex.

It seems RETScreen is able to easily model systems composed of several groups of buildings, mostly served by a central heating/cooling plants, such as universities, commercial complexes, communities, hospitals, and industrial complexes However, the modeling of microgrid-based IES is not well explored and some limited features of this tool such as low time resolution has drawn its use typically for pre-project analysis, especially in big capacity plant projects.

4.6. *H_2RES*

H_2RES is a balancing tool whose main purpose is the energy planning of islands and isolated regions which operate as stand-alone systems but it can also serve as planning tool for single wind, hydro or solar power producer connected to bigger power systems. The model was developed in 2000, by Instituto Superior Técnico (IST-UTL) along with the University of Zagreb (UZagreb). H_2RES balances between hourly time series of water, electricity, heat and hydrogen demand, appropriate storages and supply (wind, solar, hydro, geothermal, biomass, fossil fuels or mainland grid) over a user-defined term. The model considers a wide variety of thermal generation except nuclear and all renewable technologies except for tidal power. Also only compressed-air storage is not considered by H_2RES, thus technologies could vary from hydrogen loop (fuel cell, electrolyser and hydrogen storage) to reversible hydro or batteries for smaller energy systems.

H_2RES is not an economical model, but originally a RES model, being its objective function to maximize the integration of renewables in the system. The excess renewable output is either discarded or stored.

H_2RES has been used in internal projects of IST-UTL and UZagreb exclusively applied in islands, although it may be used for other kind of remote locations. In 2004, Duić and da Graça Carvalho [115] use H_2RES for the optimization of the integration of hydrogen usage with intermittent renewable energies in Porto Santo, an island in the Madeira archipelago. In 2009, Krajačić et al. [116] employ H_2RES for running a set of RE scenarios in the island of Mljet, Croatia, all of them optimized for the highest RES penetration (not economically). Scenarios included combinations of PV, wind, fuel cell and hydrogen storage technology. In general, the Scenarios analysis proven that decentralized energy generation could offer good solution for harvesting of renewable energy sources on Croatian Islands. A similar analysis was performed by Segurado et al. [117] in 2010, where different scenarios are analyzed with the objective of increasing the penetration of renewable energies in the energy system of S. Vicente Island in Cape Verde Archipelago. The scenarios considered wind, pumped hydro storage and desalination technologies. Results have shown that having more than 30% of yearly penetration of renewable energy is possible, together with more than 50% of the water supplied to the population.

The lack of experience and validation of H_2RES as a tool for performing integrated energy analysis is limitation of the tool, on the extent of this study. However, there is potential for IES planning since fuel cell hydrogen can also be used in Internal Combustion Engines with heat recovery as stationary source for CHP or trigeneration.

5. Survey results and analysis

The survey on modeling options for the local level shows a small number of tools and particularly field applications on this scale. This observation goes in accordance with the conclusions of Hiremath et al. [4] in 2005. The bottom-up tools which were analyzed in this study are compared in Tables 1–4.

Table 1 compares tools taking into account its objective function, type of system considered, solution method approach, type of tool and type of optimization done. The majority of the models perform economics-based optimization, whether this is done regarding costs accounting (normally TC) or cash-flow of the projects (NPV). In the other hand, in H_2RES, the objective function is to maximize renewable energies integration. A double-objective approach was also already used with DER-CAM, being included one CO_2 minimization objective. Further environmental terms, mainly CO_2 emissions but also NO_X, PM, SO_2, CH_4 for instance are often taken into account in the output analysis, as in the cases of HOMER, DER-CAM, RETScreen, MARKAL/TIMES. The purpose of this analysis is not only to evaluate green house gases emissions but also local air pollution impacts. In the other hand, social aspects are not considered in any of the surveyed tools, both short-term and long-term. In this context, a broader approach taking into account more profound environmental analysis would be innovative. Specifically, environmental impacts such as emissions of CO_2, NO_x, PM, CO, SO_2 (as indicators of global warming and/or air pollution) land occupation or noise disturbance can be introduced in the objective function and not only be subject of output analysis. The same line of thought can be applied from the point of view of social aspects such as promotion of new jobs, being these, however difficult to model. The Not In My BackYard (NIMBY) phenomenon could also be taken under account, trough creating an index for community opposition based on available historical facts. Naturally, these considerations are dependent on the scale of the planning exercise. ICES planning fits on the mesoscale modeling approach and in that sense the optimization problems can allow for both local and broader impacts to consider. Specifically, in the case of air pollutants, they can have local impacts (CO, PM), regional impacts (NO_x, SO_2) or global impacts (CO_2). It would be mostly interesting to explore the effects of the introduction of different configurations of ICES at these three levels.

Table 1
Timetable with the universe of referenced surveyed publications on electrical distribution systems planning, with the respective applied methods.

Name	Objective	Type of system	Solution method	Type			Optimization	
				Simulation	Scenario	Equilibrium	Operation	Investment
HOMER	min [NPC]	DG in general[a]	Accounting	√			√	√
DER-CAM	min [costs]	DG in general[a,b]	MILP/GAMS – CPLEX				√	√
EAM	min [costs]	DG in general[a]	MINLP				√	√
MARKAL/TIMES	min [costs]	user-defined	MILP/GAMS – CPLEX		√	√		√
RETScreen	min [costs]	DG in general[a] and centralized	Accounting		√			√
H_2RES	max [DG integration]	DG in general[a]	Energy balancing	√	√		√	

[a] Includes CHP, Thermally Activated Technologies, RE, etc.
[b] Currently excludes Wind Turbines (WT).

In general, most tools consider a valuable set of DG technologies, including renewables such as PV and Wind or CHP and Trigeneration technologies such as combustion engines, microturbines and absorption chillers, allowing for hybrid complementary function of systems, inherent to the concept of ICES. RETScreen features the most extensive technologies database. Additionally, battery storage is supported by all surveyed tools. Particularly, DER-CAM was already used for accessing the interactions with EV storage options [101]. The consideration of battery storage is of vital importance due to:

1. Key value of the technology on the development of microgrids, being currently the best compromise between performance and cost for this kind of systems [118,119];
2. Allowing for EV battery storage, being EV's principal to the conception of the new generation grids, for multiple environmental and economical reasons.

The solution methods are mostly dependent on LP techniques, as in EAM, DER-CAM and MARKAL/TIMES. In EAM, non-linear aspects of the functioning of DG are considered while DER-CAM and MARKAL/TIMES define the problem as a MILP. The three tools solve the problem using the capabilities of GAMS. At least DER-CAM and MARKAL/TIMES use the CPLEX solver. HOMER, RETScreen and H_2RES make use of energy balancing and accounting methods for reaching optimal decisions. The first one evaluates a large number of simulated technology combination options, ranking the technically plausible ones by the economical feasibility of the investment (NPC). One critical comparison must be made between the problem that is solved by EAM, DER-CAM and HOMER. Both EAM and HOMER require a *given* system for developing the optimization process, which means they design the appropriate capacities and mix of a user-selected set of technologies. DER-CAM's algorithm adds an assignment function to this problem, performing *technology choice* before designing the optimal capacities to apply in the system. In this sense, DER-CAM solves a three-level assignment problem in opposition to the two-level assignment problem being solved by both EAM and HOMER.

As to RETScreen, it performs a comparison of the investment of one proposed case with a base-case one. H_2RES is a simulation tool that balances the hourly time series of electricity and heat, as well as appropriate storage and supply over any user-defined period.

In the context of the objective of this study HOMER, DER-CAM and EAM feature the advantage of being both investment and operation optimization tools. MARKAL/TIMES and RETScreen perform investment-only optimization while H_2RES is exclusively concerned with the best operation conditions of the system. MARKAL/TIMES, RETScreen and H_2RES allow for scenario-oriented long-term analysis as well, which is a plus when looking at ICES deployment futures. The authors consider further more detailed environmental analysis would require life cycle approach, considering additionally the environmental impacts at least in manufacturing and elimination stages. This is especially important in the fair consideration of renewable energy DG, for instance, which feature emission factors of CO_2 which are null during operation stage but are not negligible in other stages of their lifetime, mainly during manufacturing.

Furthermore, as can be shown in Table 2, tools like HOMER, DER-CAM and EAM are specifically directed for community or project-level studies whereas MARKAL/TIMES and RETScreen allow for customization of project scale. In the case of H_2RES, the model is oriented for any scale from the regional level till the individual project one. Regarding time parameters, the same first three are short-term analysis tools, considering one typical year of system functioning. Additionally, HOMER, DER-CAM and EAM all work on hourly basis, which on system design is an appropriate resolution taking into account the constraints of required detailed description and required time of optimization. MARKAL/TIMES and RETSCreen are long-term analysis tools allowing for the consideration of a maximum time period of 50 years, in which the evolution of the system trough time is evaluated. RETScreen does not permit higher time resolution than month, which constitutes a limitation for shorter term analysis. H_2RES is a customizable tool in which the time horizon is customizable and unlimited, however the time step is hourly resulting in reduced flexibility for long-term analysis.

Table 3 features some of the aspects which are related to the user-model interface relationship. These are important issues which are not top concerns but nevertheless deserve appropriate consideration, in the task of selecting a valid tool for the purpose of this study. In general, the level of technical detail and good data management capabilities but high level of effort and lower intuitiveness of tools such as DER-CAM and MARKAL/TIMES is

Table 2
Characterization of the analyzed bottom-up energy tools, according to scale and time.

Name	Scale					Time		
	≤Community	Regional	National	≥International	multiple	Term info	Step	Horizon
HOMER	√					Short-term	Variable	1 year
DER-CAM	√					Short-term	Hourly	1 year
EAM	√					Short-term	Hourly	1 year
MARKAL/TIMES					√	Long-term	user-defined	50 years max.
RETScreen					√	Long-term	Monthly	50 years max.
H2RES	√[a]	√[a]				Unlimited	Hourly	Unlimited

[a] In this particular case, the model is specifically conceived for modeling energy systems of islands, tough it works for isolated communities in general

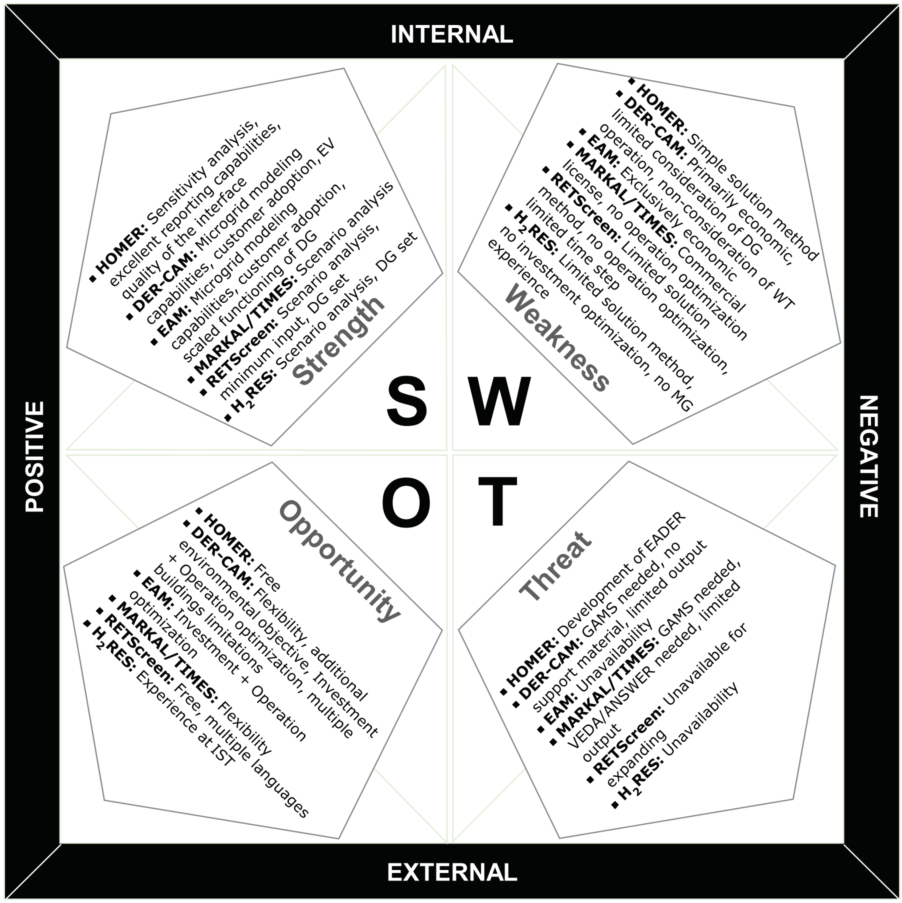

Fig. 7. SWOT analysis of the compared tools, on the extent of the objective of this survey.

Table 3
Characterization of the analyzed bottom-up energy tools, according to user friendliness and technical capabilities.

Name	Expertise required	Level effort	How intuitive	Reporting capabilities	Data management capabilities
HOMER	Medium	Low	High	High	Medium
DER-CAM	Medium	Medium	Medium	Medium	Medium
EAM	–	–	–	–	–
MARKAL/TIMES	High	High	Medium	Basic	Basic
RETScreen	Low	Low	High	Excel	Excel
H_2RES	–	–	–	–	–

highlighted. On the other hand, more intuitive tools such as HOMER and RETScren present lower levels of effort but not so good flexibility when it comes to data management. Additionally, reporting capabilities of RETScreen and especially HOMER are fairly good compared to DER-CAM and MARKAL/TIMES, in which the work of output representation and management is left to the user. EAM and H_2RES are not considered in Table 3 due to unavailability of the model to the public.

Table 4
Characterization of the analyzed bottom-up energy tools, according to the software information.

Name	Interface	Software requirements	Availability	Tech. Support	Reference materials	Language	Developer
HOMER	HOMER	Windows	Free	Email	Available online	English	NREL
DER-CAM	GAMS Input/Output Manager	Windows, GAMS, Solver and Interface	Free, GAMS needed	Email	Not available, under elaboration	English	LBNL
EAM	–	–	–	–	–	–	Univ. Tokyo
MARKAL/TIMES	VEDA, ANSWER	Windows, GAMS, Solver and Interface	Commercial	Phone or email	Manual available to registered users	English	ETSAP
RETScreen	Excel	Windows, Microsoft Excel	Free	Email or web forum, free limited	Manuals available	Multiple	RETScreen International
H_2RES	–	–	–	–	–	–	IST-UTL/Univ. Zagreb

The general characteristics of all the surveyed tools are additionally presented in Table 4. Worth mentioning are the free distribution and full availability of technical support and reference materials for both HOMER and RETScreen. In the case of RETScreen the interface is provided in multiple languages. These factors mostly contributed to the widely spread success of these two tools on the Energy market. On the contrary, both DER-CAM and MARKAL/TIMES require the acquisition of a commercial version of GAMS with CPLEX solver and of the specific interface. In the case of DER-CAM a user manual still does not exist, as this is being currently developed by LBNL. Due to present unavailability to public users, there is no record of reference materials for both EAM and H_2RES.

Fig. 7 shows the final SWOT analysis of the surveyed models, on the extent of the current study, where all the aspects discussed in this chapter are graphically explained.

6. Conclusions

Integrated Community Energy Systems (ICES), capable of delivering sustainable electricity, heat and cold to small populations and of working as isolated islands or as a back-up of the distribution network, constitute a viable approach for dealing effectively with the new set of global problems which Mankind is facing. Additionally, due to the many potential benefits related to the introduction these systems, the need for using, developing or expanding viable tools for incorporation of all the relevant sustainability factors in ICES planning and analysis is urgent.

In this context, a number of energy bottom-up tools were subject to analysis in Section 3, addressing also special concerns to the incorporation of the environmental, economical and social aspects of Sustainability. The analysis was done in Tables 1–4, taking into account a number of criteria, such as type of system modeled, objective function structure, scale, time factors.

Ultimately, DER-CAM and EAM can be considered preferable tools for the purpose of ICES design modeling, mainly due to the several successful applications with modeling microgrid systems. HOMER is also a valuable tool in which the authors recognize these capacities. Nevertheless, DER-CAM has advantages over both EAM and HOMER regarding firstly the three-level assignment algorithm, which is superior in terms of design optimization, but also the availability of this tool for being explored and expanded. EAM is being mainly utilized as an internal research tool being currently not available to the general public. Additionally, DER-CAM's objective function has been modified in the past to include environmental objectives and there is experience in modeling the EV interactions with buildings. These two aspects have increased importance due to the new trends of sustainability-sound modeling and EV's battery consideration in ICES vision. Moreover, GAMS is widely known for allowing changes to be made in model specifications simply and safely, which is an advantage of using DER-CAM regarding future improvements for the purpose of adequate ICES planning. More detailed environmental analysis would require life cycle approach, considering additionally the environmental impacts at least in manufacturing and elimination stages. As to the introduction of social aspects in the objectives of the modeling functions it is found this research area is unexplored and certainly there are opportunities for further analysis on this topic.

Finally, MARKAL/TIMES is a tool that has additional interest for analyzing the long-term deployment of ICES in time. The literature shows that there is flexibility in this tool for modeling systems of any scale. Adding to this, it is possible to adjust the time slices of the model, one approach which was already reported in the literature with success [107]. In this context, increase of detail is allowed, which can possibly be needed in such small systems. Thus, the survey highlights that LP can be successfully applied both in short-term (DER-CAM, EAM) and long-term (MARKAL/TIMES) modeling problems, as Hiremath also concluded in [4].

The authors recognize the multiple capabilities of especially HOMER but also of RETScreen for performing IES analysis. There are however, a number of characteristics which fall out of the most desirable ones on a readily usable or expandable tool for developing this kind of evaluation. Specifically, RETScreen is a tool that fits quick pre-project both technical and economical evaluation of DG, leaving more dense and input-demanding optimization for other heavier energy models. The two tools win credits specially for the intuitiveness and graphical richness demanded by public users. Moreover, RETScreen is not applicable to short-term analysis due to low time resolution offered. Additionally RETScreen does not perform pure economical optimization while there is also the issue of difficulties in expansion of such package. As to H_2RES, it was specially designed for renewable sources modeling, although potentially allowing for the consideration of community IES. Moreover, H_2RES does not take into account the economics of DG introduction making it a non-reliable option for the purpose of sustainability economics-sound planning. Adding to the referred aspects, the lack of referenced studies on the modeling of ICES of all the three tools is a concern, which highlights the immaturity of these tools for such purpose. In the case of DER-CAM and EAM, there is past experience and consequent modifications for the purpose of modeling IES.

Systems Thinking is highly valuable as an approach for designing energy futures. In this context, grouped implementation of ICES, relying on integrated microgrids is a feasible alternative for delivering energy to the consumers in the near future. These systems bear the potential for representing part of the solution for global sustainability issues, which governments will have to deal in the concurrent decades. The present paper overviewed the approach of ICES and of its structural units, surveying available tools for the highly required planning and analysis of these systems. A group of tools were identified which can be on the basis of future developments in this field. Future work can include sustainability-sound modeling for optimal design of ICES and deployment scenario options evaluation, through long-term time horizons consideration.

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